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COMPUTER UTILIZATION OF TIME-LINE MEDICAL DATA FROM MAN IN SPACE FLIGHT

by Jefferson F. Lindsey

NASA Headquarters
Washington, D. C.

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COMPUTER UTILIZATION OF TIME-LINE MEDICAL DATA FROM MAN IN SPACE FLIGHT

Jefferson F. Lindsey, Ed.D.*

SUMMARY

The NASA medical data program is designed to contribute to (1) the safety of the astronauts while in flight, (2) the development of scientific products, and (3) the standardization of in-flight and ground-based medical data so that they are in a standard and mutually interchangeable form for computer input and analysis.

A time-line approach has been developed for accomplishing these purposes. It involves preparing medical data both on magnetic tape and on consecutive data sheets for appropriate portions of all NASA manned space flights. Each data sheet shows the physician all relevant information of interest for a specified time interval - a 10-second interval during stressful periods such as exit and reentry, and a one-minute interval during weightlessness. Data on each successive data sheet includes analog and digital indicators of astronaut beat-to-beat heart rate, pulmonary ventilation, and various spacecraft environmental as well as astronaut performance measures. Identical types of data pertaining to each astronaut have been recorded for comparable time periods for each of the six manned Mercury space flights and the Gemini flights to date, e.g., the periods of exit and reentry, and periods when identical functions were being performed. Selected ground-based medical data also have been prepared in this manner.

Examples of types of analyses that have been performed together with limitations are discussed. Several aspects are discussed under the following four categories: graphical analyses, rate-of-change and rate-of-rate-of-change analyses, some computer programs for statistical analyses, and statistical model limitations.

These data are retrievable and "on-call" for computer inputs, lending themselves to many applications. They can be brought quickly to bear on relevant past or future problems; the particular method of analysis can be decided by the investigator since raw data in both analog and digital form

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*From Directorate of Space Medicine, Office of Manned Space Flight, Headquarters, NASA, Washington, D.C.

are available. As improved methods of analysis are developed these newer methods can be applied using the available basic data. Finally, since standard scores are incorporated in the time-line data, scientists in other disciplines can, under certain circumstances, convert their data to standard scores and conduct analyses to determine relationships.

An ultimate goal is to develop a standardized method to record and store on magnetic tape all useful medical data on a world-wide basis for immediate retrieval in connection with the solution of medical problems to benefit mankind. NASA has already taken the first step in this direction. The NASA approach for space medicine data has been presented in this paper. It can serve as a building block and is open for review, criticism, revision, combination with other approaches, or redirection. These are some of the steps by which progress can be made toward the ultimate goal.

INTRODUCTION

The Medical Data Program of the National Aeronautics and Space Administration (NASA) is designed to meet three main objectives. These objectives are directed towards (1) safety of the astronauts while in flight, (2) the scientific products that can be derived from the total NASA space program, and (3) the standardization of all NASA in-flight and ground-based medical data so that they are in a mutually interchangeable form for computer input and analysis. The achievement of these objectives provides a basis for facilitating international exchange of space medicine medical data contributing to the welfare of mankind.

Accomplishment of the first objective - safety - involves the acquisition and proper utilization of all available medical data bearing directly on the safety of the space crewmen while they participate in space missions. These data, therefore, must be in a readily interpretable form so that physicians responsible for monitoring the medical aspects of space missions can utilize them to assess the well-being of the space crewman and take appropriate action at any given moment while the mission is in progress. This requires that appropriate telemetered in-flight data of the on-going mission be presented to the physician in such a form that he can compare them immediately with medical data previously acquired both during ground-based studies and space missions.

Data pertinent to the second objective - scientific products to be derived - must also be in a readily interpretable and standard form for purposes of comparison, interpretation, and prediction. There is no critical urgency, however, for the simultaneous read-out and immediate application of these data because they are utilized for the longer range scientific products

applicable to: (1) advances in medical science and technology, (2) increased safety of crews for future flights, (3) prerequisites for more extensive flights, (4) development and design of spacecraft equipment involving man-machine relationships, and (5) improved criteria for the selection and training of space flight crew personnel.

The third objective - standardization of data for computer utilization - involves the first two objectives since they cannot be accomplished satisfactorily, efficiently, and expeditiously unless the third objective is met. Accordingly, all NASA medical data, both past and future, and both in-flight and ground-based data, must be recorded and prepared on magnetic tape in a standard manner so that they are in a mutually interchangeable form. By using a proper standardized form or language, these data can be retrieved from computers and brought to bear on specific past problems, as well as to on-going and future problems that may arise during or after future space missions. It is necessary that the computer programs be prepared in advance for the various graphical, mathematical, and statistical analyses to be performed so that immediate interpretation can be accomplished.

Consideration must be given to the specific in-flight and ground-based medical data prepared for computer inputs. The in-flight medical data telemetered to earth for medical monitoring during the six manned missions of the Mercury program and the Gemini manned space missions conducted up to the present time consisted of three types: physiological, spacecraft environmental, and operational performance. The physiological data for each astronaut included electrocardiographic (ECG) records, respiration, pulse, body temperature, and blood pressure. The spacecraft environmental data included acceleration, space suit inlet temperature, suit outlet temperature, carbon dioxide partial pressure, and cabin pressure. The operational performance data were restricted, for the most part, to what each astronaut was doing and saying. Aeromedical preparation and aeromedical observations, respectively, for the Mercury data have been presented concisely by Berry (1) and by Catterson, McCutcheon, Minners, and Pollard (2).

Ground-based medical data consist of many types. Some of the more important types are: mission simulation data, astronaut clinical medical history data, and baseline data. The mission simulation data for the Mercury, Gemini, and Apollo programs include information obtained during studies in which a space mission in whole or part is duplicated, insofar as practicable, in our earthly environment. These studies are accomplished by use of such devices as a centrifuge, space chamber, mission simulator, procedures trainer, and by conducting immobilization studies. The medical data acquired during these simulations include those obtained during actual space mission. In most cases, however, the data are far more extensive as indicated by Chambers (3) and in a preliminary paper by Fraser (6).

The clinical medical history type of data for each astronaut have been entered in the cumulative medical records noted by physicians during periodic physical examinations over a number of years as shown by Lovelace, Schwichtenberg, et al (10) and Link (9). In addition, these data can be supplemented by the physiological and psychological test data acquired during the astronaut selection program. Lovelace et al (10) have described four phases of the astronaut selection program in addition to a machine record system to facilitate recording and analyzing medical data. Wilson (16) has described the third phase of the selection program including the tests administered and the results obtained. Also included as part of the clinical medical history are data obtained immediately before and after each space mission. These are necessary to conduct studies relevant to any significant physiological change that may have occurred as a result of the space flight. An example of these data is given by Minners, Douglas, Knoblock, Graybiel and Hawkins (11).

The baseline data includes data available in the medical literature which indicate norms and tolerances for human beings with respect to medical measurements that have previously been established under specified conditions. A discussion of baseline data requires little elaboration except to point out that it includes baseline data for a highly selected sample, the astronauts, as well as general baseline data available in the medical literature.

As previously stated, in establishing the NASA space medicine data program, one of the prime objectives was to prepare all appropriate medical data in a standard mutually interchangeable format suitable for computer inputs. The question naturally followed: What type data should be used initially for establishing the pattern toward which all other types of data could be related? As a result of a comprehensive study, the in-flight type of medical data was selected for this purpose and although extremely limited at first, these data now include those obtained during the Mercury program and from the Gemini missions conducted to date. As the Gemini program progresses, the size of the sample in-flight data will increase permitting even more extensive analyses.

Several considerations were involved in making this decision to pattern the preparation of all space medicine data after in-flight medical data. First, in-flight data are the most difficult to obtain and once the space mission has started, there can be no turning back or re-doing the flight, as would be possible in most ground-based physical examinations, tests, simulations, or medical experiments. Second, these in-flight data are highly important and valid information to consider in analyses because they provide information about the precise reactions of space crewmen under actual space flight conditions. Third, the in-flight data have a direct bearing on astronaut safety and since attention must be focused on some

selected aspect of such a comprehensive program, it would be better to place the initial emphasis on data having a direct bearing on safety of flight. Finally, in large part, the analyses of in-flight data serve as an indicator of future data requirements both for ground-based studies and space missions.

The next questions to be answered were: How can in-flight medical data be prepared for immediate (instantaneous) use by the medical monitors of each space mission and for expedient post-flight analyses? At the same time, how can all NASA medical data be prepared in a form for computer inputs utilizing both in-flight and ground-based data?

In seeking answers to these questions, the time-line presentation was developed. The remaining portion of this paper will be devoted to an explanation of this concept and its application, focusing attention upon in-flight medical data. The inductive leap necessary to conceptualize how this same approach can be used in connection with ground-based medical data will, for the most part, be left to the reader, since these applications are beyond the scope of the paper.

PREPARATION OF TIME-LINE MEDICAL DATA

General

In the time-line analysis approach, data sheets are constructed representing successive time intervals. The approach can best be presented by describing how the in-flight medical data of the manned Mercury flights and the Gemini flights have been prepared for computer inputs in a standard, magnetically taped format. All relevant information available for a given time interval of short duration was printed on one data sheet by use of a computer, and its associated equipment. This included all available space flight information of value to the physician concerning the well-being of the astronaut for the specific time interval represented. Since the physician is interested in a composite presentation of all relevant information during any given time interval, each data sheet included astronaut physiological data, spacecraft environmental data, and astronaut performance data. Thus, the physician can appraise the relationships within, and interactions among, these various factors. Additional data sheets were constructed for consecutive time intervals. Each of these consecutive data sheets showed the identical type measurements as shown on the preceding data sheet but of course the entries were different in value because they pertained to different time intervals.

The requirement for the duration of the time intervals for data sheets was different for various portions of the mission because the physician is interested not only in change, per se, but also in the rate-of-change and the rate-of-rate-of-changes of both physiological reactions and environmental conditions. These kinds of changes generally take place more rapidly during the stressful conditions which occur immediately before lift-off (e.g., the two-minute period prior to "lift-off"), and during exit and reentry. Generally, less stressful portions of a mission occur during weightlessness and the periods prior to flight (e.g., one hour before flight) and after flight. Thus, data sheets covering the short interval of 10 seconds were selected for the stressful portions of the missions, whereas data sheets covering a one-minute interval were selected for less stressful portions of the missions. This can be shown more clearly by describing the blocks of data sheets selected for use in connection with the various types of analyses to be performed.

Description of Blocks of Data Selected

The first block or group of successive data sheets for each mission included a series of fifteen consecutive one-minute time intervals covering the period from one hour before lift-off (T minus 60) to forty-five minutes before lift-off (T minus 45). The first data sheet or tabulation (Tab) in this group covered the one-minute time interval starting at T minus 60 and lasting until T minus 59 minutes. The next consecutive one-minute interval covered the period T minus 59 to T minus 58; the next, T minus 58 to T minus 57; and so on until 15 consecutive data sheets were printed. This block of 15 separate data sheets covered the period from T minus 60 to T minus 45 for each manned space flight as show in Table 1. This will be extended to include additional Gemini missions and the Apollo space missions and simulated missions.

The next group or block of data sheets included the series of consecutive time intervals covering the period T minus 120 seconds (T minus 2 minutes) to T zero in 10-second intervals as shown in Table 2. The sample size here will also be extended using data from future missions, and past and future simulated missions.

The next block of consecutive data sheets covered the period T zero to the onset of zero "g" in 10-second time intervals since this was a stressful period of each mission. The next block of consecutive data sheets covered the period from T plus 30 minutes to T plus 45 minutes in one-minute intervals, since these data were obtained during weightlessness, that is, during less stressful portions of the missions. Carrying this process out to its conclusion, there were a number of selected blocks of consecutive time intervals chosen for detailed analyses. These blocks of data covered periods when

Table 1 - Illustration of the Matrix of Data Sheets for the Period from T minus 60 to T minus 45 Minutes

	T-60 to T-59	T-59 to T-58	T-58 to T-57	T-57 to T-56	T-56 to T-55	T-55 to T-54	T-54 to T-53	T-53 to T-52	T-52 to T-51	T-51 to T-50	T-50 to T-49	T-49 to T-48	T-48 to T-47	T-47 to T-46	T-46 to T-45
1st Suborbital (MR 3)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2nd Suborbital (MR 4)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1st Orbital (MA 6)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2nd Orbital (MA 7)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
3rd Orbital (MA 8)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
4th Orbital (MA 9)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
1st Gemini (GT 3)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
2nd Gemini	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
x = one data sheet															

Table 2 - Illustration of the Matrix of Data Sheets for the Period T minus 120 Seconds to T Zero

	T-120 to T-110	T-110 to T-100	T-100 to T-90	T-90 to T-80	T-80 to T-70	T-70 to T-60	T-60 to T-50	T-50 to T-40	T-40 to T-30	T-30 to T-20	T-20 to T-10	T-10 to T-0
1st Suborbital (MR 3)	x	x	x	x	x	x	x	x	x	x	x	x
2nd Suborbital (MR 4)	x	x	x	x	x	x	x	x	x	x	x	x
1st Orbital (MA 6)	x	x	x	x	x	x	x	x	x	x	x	x
2nd Orbital (MA 7)	x	x	x	x	x	x	x	x	x	x	x	x
3rd Orbital (MA 8)	x	x	x	x	x	x	x	x	x	x	x	x
4th Orbital (MA 9)	x	x	x	x	x	x	x	x	x	x	x	x
1st Gemini (GT 3)	x	x	x	x	x	x	x	x	x	x	x	x
2nd Gemini	-	-	-	-	-	-	-	-	-	-	-	-
x = one data sheet												

Table 3 - Mercury Bio-Medical Data Requirements

	15 MINUTE PERIOD @ 1 MIN SAMPLES AT A COMMON TIME BETWEEN T-60 MIN AND T-2 MIN	T-2 MIN. TO LIFTOFF @ 10 SEC SAMPLES	LIFTOFF TO ZERO g @ 10 SEC. SAMPLES	ZERO g TO + 15 MIN @ 1 MIN SAMPLES	ZERO g + 30 MIN TO ZERO g + 45 MIN	PERIOD OF ASTRONAUT ACTIVITY	SLEEP	RETRO SEQUENCE -90 MIN TO -75 MIN BASED ON MA-6 & MA-7	RETRO SEQUENCE -90 MIN TO -75 MIN BASED ON (MA-8)	RETRO SEQUENCE -90 MIN TO -75 MIN BASED ON (MA-9)	RE-ENTRY SEQUENCE -15 MIN TO .05g BASED ON MA-6 & MA-7	RE-ENTRY SEQUENCE -15 MIN TO .05g BASED ON MA-8	RE-ENTRY SEQUENCE -15 MIN TO .05g BASED ON (MA-9)	.05g TO LANDING	POST - LANDING
MR - 3	15 MIN DATA CONTINUOUS 15 TABS	2 MIN DATA 12 TABS	2 MIN 40 SEC DATA 16 TABS	ONLY 5 MIN OF DATA 5 TABS										00:07:50 TO 00:15:37 47 TABS	LANDING+5 MIN 1 MIN SAMPLE 5 TABS
MR - 4	"	"	"	ONLY 5 MIN OF DATA 5 TABS										00:07:50 TO 00:15:37 47 TABS	"
MA - 6	"	"	5 MIN DATA 30 TABS	15 MIN DATA 15 TABS	15 MIN DATA 15 TABS	00:25:00 TO 00:30:00 5 TABS		3:09:08 TO 3:24:08 15 TABS			4:29:03 TO 4:44:03 15 TABS			4:44:03 TO 4:55:23 68 TABS	"
MA - 7	"	"	"	"	"	3:52:00 TO 4:07:00 15 TABS		"			"			4:44:03 TO 4:55:57 72 TABS	"
MA - 8	"	"	"	"	"			"	7:22:00 TO 7:37:00 15 TABS		"	8:46:40 TO 9:01:40 15 TABS		9:01:40 TO 9:13:11 70 TABS	"
MA - 9	"	"	"	"	"	2:19:00 TO 2:34:00 15 TABS	13:59:00 TO 15:03:00 27 TABS	"	"	32:29:30 TO 32:44:30 15 TABS	"	"	33:53:36 TO 34:08:36 15 TABS	34:08:36 TO 34:19:49 68 TABS	"
MA - 9									25:00:00 TO 25:15:00 15 TABS						"
TOTAL	90 TABS	72 TABS	152 TABS	70 TABS	60 TABS	35 TABS	27 TABS	60 TABS	45 TABS	15 TABS	60 TABS	30 TABS	15 TABS	372 TABS	30 TABS

TOTAL 1133 TABS

the astronauts were involved in such functions as exercising (performing identical exercises), resting or sleeping, performing or monitoring retro-fire operations, exiting, and landing. A detailed chart showing the specific periods chosen is shown in Table 3.

A study of the information included in Table 3 will provide an insight as to how comparisons and statistical treatments of time-line data can be accomplished. It becomes obvious that data from one mission can be compared with data pertaining to other missions within certain limitations. Also, measurements taken at the early part of any given mission can be compared with those taken during the latter part of selected portions of the same mission to assess changes that may be taking place. Furthermore, when data are prepared in the manner described, it is not necessary to restrict the analyses to the time intervals represented by each data sheet; i.e., 10-second or one-minute intervals. If, for example, one has 15 consecutive one-minute data sheets, the computer can be programmed to treat these data either as a consolidated or as a segmented block of data of any desired length in minutes or portions thereof such as 15, 10, 5, 3, 1, 1/2, 1/4, or 1/8. The same is true of the 10-second interval data sheets.

Description of Data Sheet Content

A detailed examination is now in order concerning the specific information that was included on each data sheet. This will be accomplished in concert with an illustration of a data sheet for a selected 10-second interval as shown in Table 4 and Figure 1. Data sheets for the one-minute intervals were identical in format, except that no acceleration data were included since the one-minute intervals are applicable to periods of the missions either before flight, during weightlessness, or after flight where no acceleration forces were present. Therefore, for all practical purposes, the following discussion of the 10-second type of data sheet will suffice. The discussion is keyed to the illustration shown in Table 4 and Figure 1.

Heading: The heading for each data sheet contained information identifying the data as time-line data, indicating the mission from which the data were taken, the mission elapsed time, and the date of the mission. In the example shown in Table 4, it may be noted that the time-line data were taken from a Mercury-Atlas mission, MA-9. The mission elapsed time encompassed the 10-second interval from 20 seconds to 30 seconds after lift-off on May 15, 1963.

The reason for including the information presented is obvious. Each

Table 4 Example-Data Sheet For 10-Second Interval

TIME-LINE DATA

PROJECT MERCURY
MERCURY ATLAS NO.

MISSION ELAPSED TIME = 00,00,20 TO 00,00,30
DATE

HEART RATE BEATS/MIN	STANDARD SCORE	RESPIRATION RATE BREATHS/MIN	STANDARD SCORE	ACCEL. Z-AXIS G-S	STANDARD SCORE	SUIT-IN TEMP DEG F	SUIT-OUT TEMP DEG F	CO2 PARTIAL PRESSURE PSIA	CABIN PRESSURE PSIA
115.60	38.20	16.90	36.40	1.77	50.30	65.22	84.52	.0000	15.245
112.14	36.79	15.78	35.39	1.90	50.96	65.18	84.46	.0000	15.213
112.14	36.79	22.72	41.63	1.77	50.30	65.22	84.52	.0000	15.198
113.85	37.49			1.71	50.00	65.26	84.58	.0000	15.229
115.58	38.19			1.71	50.00			.0000	15.229
115.60	38.20	⬌		1.64	49.65	⬌	⬌	.0000	15.245
113.85	37.49			1.37	48.28			.0000	15.276
115.60	38.20	⬌		1.90	50.96	⬌	⬌	.0000	15.198
112.14	36.79			2.43	53.65			.0000	15.198
113.85	37.49	⬌		2.04	51.67			.0000	15.198
113.85	37.49			1.71	50.00	⬌	⬌	.0000	15.174
115.58	38.19			1.90	50.96			.0000	15.158
119.28	39.69						****		****
121.18	40.46	⬌		⬌		⬌	MEAN ⬌	⬌	MEAN ⬌
121.18	40.46								
123.20	41.28			⬌		65.22	84.52	.0000	15.216
121.18	40.46	⬌							
119.26	39.68			⬌					
123.17	41.27	⬌							
123.20	41.28								
⬌		⬌		⬌					
******	******	******	******	******	******				
MEAN =	117.07	MEAN =	18.46	MEAN =	1.82				
SIGMA=	3.96	SIGMA=	3.72	SIGMA=	.25				
VARIANCE=	15.68	VARIANCE=	13.88	VARIANCE=	.06				

ACTIVITY

1. PLANNED — START BACKUP CLOCK.
2. INDICATED — START BACKUP CLOCK.

COMMUNICATIONS

00,00,20	CC	MARK.
00,00,23	P	ROGER. AND THE BACKUP CLOCK IS RUNNING
00,00,25	CC	ROGER. YOU LOOK GOOD HERE, GORDO.
00,00,27	P	ROGER. FEELS GOOD, BUDDY.
00,00,29	CC	GOOD SPORT.

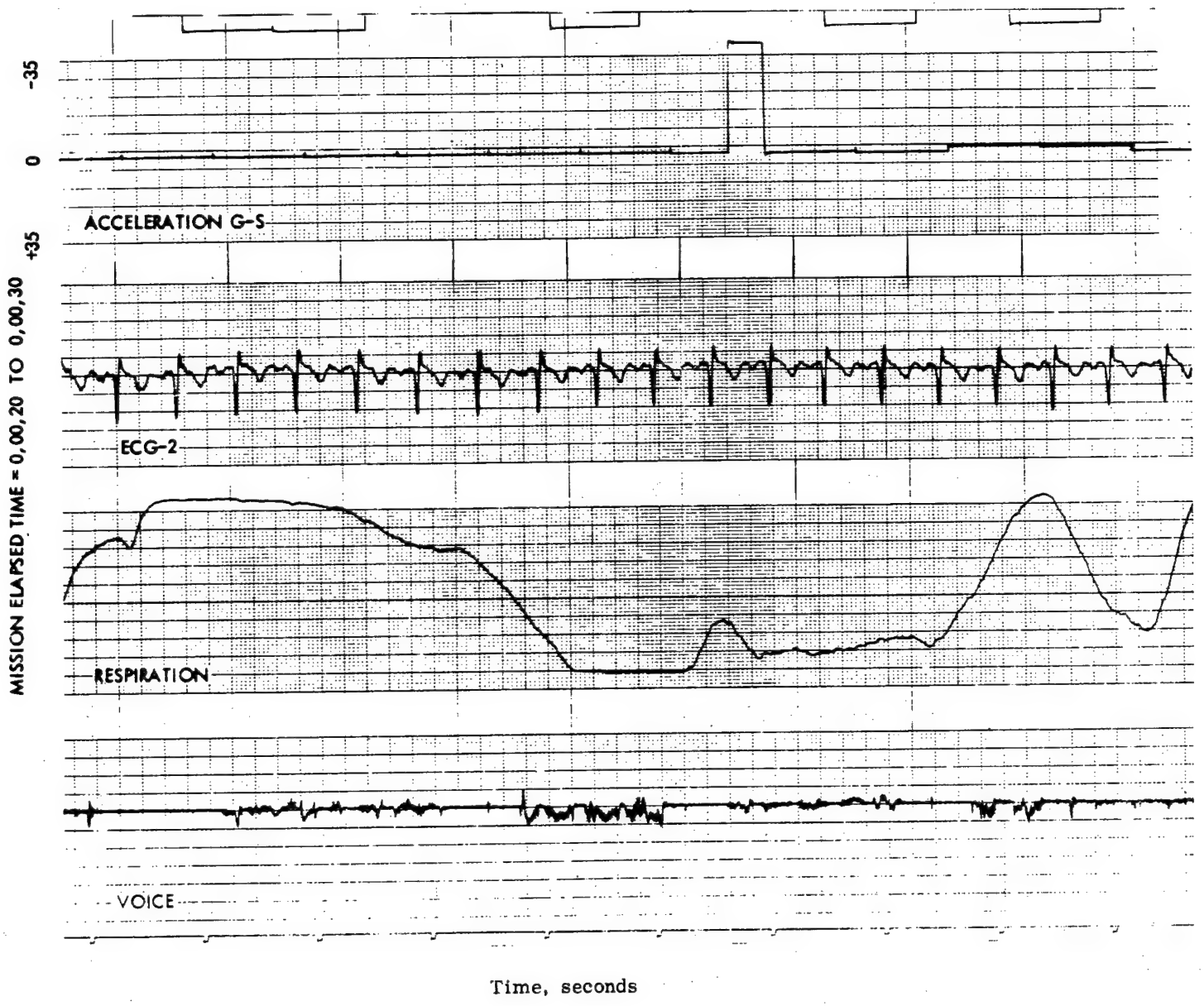

Figure 1 Example-Data Sheet for 10-Second Interval

data sheet must be an identifiable entity in itself to be used by the computer for analytic purposes.

Heart Rate: The rate of the astronaut's heart beat in beats per minute (R to R) is shown for each beat that occurred during the 10-second time interval represented. In the example, there were approximately two heart beats per second since the mean for the 10-second interval is very nearly 120. More precisely, the mean was 117.07. Since the heart does not beat at a constant rate, it was possible to solve for the standard deviation (Sigma) and the variance for the time interval represented. The second column under Heart Rate shows the standard score for each of the beats represented in the first column. These standard scores or "z" scores were calculated by using all of the heart rate data points within a pre-defined period of time for any given mission, e.g., all data points during the combined periods of exit and reentry, and then finding the mean and standard deviation of the distribution of these data. From this, the standardized score or "z" score was calculated for each heart rate data point in column 1. Since "z" scores contain negative numbers, a new distribution (standardized score) was formed with a mean of 50 and a standard deviation of 10 by multiplying each "z" score by 10 and adding 50. The standardized scores for any given mission in progress cannot be computed instantaneously as the space mission progresses since all data points in the distribution (exit and reentry, in this example) must be known before the calculations can be made. However, the standardized scores for each heart-rate data point can be calculated instantaneously if the distribution has already been established during previous missions. Detailed methods for making the calculations discussed under this heading may be found in standard textbooks such as those written by Dixon and Massey, (4), Edwards, (5), and Weinberg and Schumaker (15).

Again, the reasons for obtaining and printing digital heart-rate data on each data sheet is obvious, but justification for calculating means, standard deviations, and standard scores, requires at least brief amplification. The means and the standard deviations can be graphically printed by the computer for presentation to the physician as the space mission progresses to indicate any trends or patterns that may be developing in heart rate. These statistics can also be used in connection with various graphical, mathematical, and statistical analyses as will be explained later. The standard scores, based on a mean of 50 and a standard deviation of 10, provide the physician with definite information as to how near normal the heart is beating in comparison to what should be expected at any given time and circumstance for the astronaut(s) participating in the space mission. For example, if the standard score is 50 (the mean), the physician would know that this was the average rate for the astronaut, considering all heart beats to be expected during exit and reentry. If the standard score is 40, he would know this particular beat was one standard deviation below the mean. Additionally, by converting to standardized scores, instead

of using "z" scores, one eliminates the necessity of working with negative numbers. This is generally convenient, and in some cases necessary, when conducting certain types of analyses. Finally, by converting not only heart-rate data but also respiration rate and acceleration rate data to standard scores, it becomes possible to compare these diverse types of measurements to one another using a standard base (standard score). Accordingly, various additional analytic techniques become available for use.

Respiration: The respiration rate, in breaths per minute, for the 10-second interval are shown (Table 4) and the standard score is shown for each entry. The standard scores are based on all respiration-rate-data points covering the same time period for the mission as was used in calculating the heart-rate standard scores -- in this instance, exit and reentry. Also, as in the case of heart-rate data, the mean and standard deviation are shown for the respiration data for the 10-second interval represented. The rationale for including the foregoing respiratory information on each data sheet was similar to that previously described - when using several consecutive data sheets, one can begin to identify existing trends, patterns, and relationships.

Other Measurements: Other physiological measurements mostly of a periodic nature were taken but are not shown, since they are not applicable to the 10-second interval data sheet being used here for illustrative purposes.

Environmental Measurements: As shown in Table 4, these measurements include acceleration, space suit inlet and outlet temperatures, carbon dioxide partial pressure, and cabin pressure. The data sheets included rate information for each of these parameters plus the mean, standard deviation, and standard scores for acceleration data. Only the mean was calculated for the other spacecraft environmental measurements. One can see now that trend information for spacecraft environmental measurement becomes available and also data pertaining to relationships both within and among physiological and spacecraft environmental aspects of space flight.

Activity: One type of operational performance data of a continuous nature readily available for incorporation in the selected data sheets was a description of both the planned and actual activity of the astronaut during the time interval represented. As shown in Table 4, the astronaut was supposed to start the backup clock during the 10-second time interval and he accomplished this task.

By recording the planned as well as the actual activity, one is able to tell if the astronaut is on schedule, ahead of schedule, or behind schedule, and assess the implications related thereto. However, in order to utilize these data digitally for analytic purposes in relation to physiological and spacecraft environmental data, it was necessary to construct

Table 5 - Types of Activities

Criticalness (C)	Difficulty (D)	Duty (T)	Procedure (P)
1C. Highly Critical	1D. Very Difficult	1T. New (performed in spacecraft only)	1P. Active
2C. Medium Critical	2D. Medium Difficult	2T. Revised (combination of old and new)	2P. Passive
3C. Non-Critical	3D. Easy	3T. Old (previously performed in aircraft)	3P. Concurrent
			4P. Shared (with ground personnel)

operational definitions for each type of activity. These definitions were sub-divided into four areas with numerical values or weights assigned to each as shown in Table 5.

Voice: Another type of indirect operational performance indicator as well as an indicator of the well-being of the astronaut was the voice data. This was supplemented by the communications with ground crew personnel. Table 4 shows the communications that took place between ground crew personnel and the astronaut during the 10-second interval.

Many types of analyses are possible using voice data. These range from assessing the state of the astronaut's alertness and probable relationships associated therewith to analyses pertaining to speech processes, audiology, and information processing. (See Starkweather (13). The physician can obtain considerable information about the condition of the astronaut merely by listening to his voice and conversing with him. Here again, though, to utilize voice data in the computer, it is necessary to digitize voice content; and, therefore, operational definitions are required encompassing areas such as probable attention, joy, fatigue, confusion, and relief. Factors considered in classifying according to these areas include voice pitch, timbre, speed, and in some cases the quickness of response of the astronaut to questions or instructions received from ground personnel. The latter, however, must be assessed and weighed with extreme care because, a response from the astronaut may not be immediate due to overriding operational functions in which the astronaut may happen to be engaged at the time the response is requested. Consideration must also be given to the fact that astronauts are a highly selective group with exceptional ability. They are conditioned to excitement and stress. Therefore, very little degradation in their voice content may be more significant than changes with respect to the normal population.

Wave Train Data: The wave train data consisted of analog read-outs of the electrocardiogram, respiration, acceleration, and voice as shown in Figure 1. These are required for two main purposes. First, they are used to check the correctness of the digital data on the data sheet, and second, they are used in connection with certain types of pattern and wave-form analyses.

TYPES OF ANALYSES

General

When data are prepared in time-line format and are available on magnetic tape as described, many types of analyses can be performed that have a direct application to the safety of astronauts while in flight and to scientific products derivable from space medicine data. Several aspects relative to these analyses together with limitations will be discussed under the following four categories: graphical analyses, rate-of-change analyses, some computer programs for statistical analyses, and statistical model limitations.

Graphical Analyses

One-dimensional graphs of the means, variances, and standard scores can be plotted for comparable time periods for each astronaut on all measurements or for all astronauts on one selected measurement. For example, the graph of heart-rate for the five-minute period immediately after lift-off consists of 30 data points - one for each 10-second interval shown on each data sheet for five consecutive minutes. Two-dimensional graphs have also been constructed showing, for example, heart-rate on the vertical axis and acceleration on the horizontal axis. Additionally, three-dimensional graphs can be constructed using various colors for the third dimension.

Although most of these graphs can be plotted by the computer in real time as a mission progresses, it is necessary to compare this information with previously acquired data in order that it may be meaningful to the medical monitors. Therefore, the necessity exists for using overlays whereby graphic information concerning the on-going mission can be superimposed over previously constructed graphs based on time-line data acquired from completed space missions or simulated missions. Overlays are also useful in comparing data acquired early in any given mission with data acquired after the mission has been in progress for many hours.

An often overlooked use of these graphs is that they provide the analyst with a vehicle for making quick, visual inspections of data. These inspections can lead to clues as to the nature of relationships that may exist within and among physiological, environmental, and performance factors. Using these clues, hypotheses can be formulated and tested using appropriate mathematical and statistical methods and models.

Rate-of-Change Analyses

The rate-of-change and the rate-of-rate-of-changes in physiological measures, such as heart rate, under various environmental conditions offers a sensitive index of the physiological reactivity of the astronaut to his environment. If one is interested in rates of change that occur within 10-second and one-minute intervals, then the variance entry on each data sheet can be used as an index for this purpose. However, if one is interested in rate-of-change information based on intervals different from those calculated and shown on each data sheet, then the instantaneous heart rate raw data on each data sheet must be used, since the summarizing effect of variance would average out information concerning the variability for these other time intervals.

In attempting to quantify rate information, one might expect that the curve for the first and second differentials of heart rate data would provide a measure of rate-of-change and rate-of-rate-of-change, respectively. This is not the case, however, because of several considerations. First, there is an assumption for the process of differentiation which requires that measurements taken be continuous. Instantaneous heart rate is not continuous in a measurement sense. Second, since in the case of heart rate one is talking about a period of perhaps 15 minutes as being a meaningful time interval, one must think about the difficulty of fitting a curve to the variations in heart rate over that period of time. Differential calculus does not work well under conditions of long time intervals and irregularly shaped curves. Third, to quantify rate information it is highly desirable and necessary to arrive at a single number to represent the rate-of-change and the rate-of-rate-of-change of each astronaut. How one would get this quantification from the equation for a curve, poses a difficult problem. Fourth, a desirable product would be the determination of significance of differences existing between two astronauts with respect to their rate-of-change and rate-of-rate-of-change characteristics. Here again, calculus does not provide a basis for this determination.

The solution seems to lie in using the concept of differentiation where it applies and in using other techniques to modify the concept where it does not apply as set forth by Townsend (14). The method for accomplishing this is described as follows (See Table 6):

Column 1 contains 15 entries of heart rate data on subject A for a given period of time. Column 4 shows 15 entries of heart rate data on subject B for a given period of time. If these heart rates were calculated one each 10 seconds, then the interval would span 150 seconds, or two and one-half minutes for each set of data. (One can use raw data instead of 10-second averages if assessment is required for a smaller incremental rate of change.)

The mean heart rate of subject A for the 15 entries during the recorded period is 82.9 beats per minute. His variability is 1.44 beats per minute.

Table 6 - Hypothetical Heart Rate Data and Their Statistical Treatment

(1) Subject A Heart Rate (HR)	(2) $\frac{d(HR)}{dt}$	(3) $\frac{d^2(HR)}{dt^2}$	(4) Subject B Heart Rate (HR)	(5) $\frac{d(HR)}{dt}$	(6) $\frac{d^2(HR)}{dt^2}$
87			87		
	1			2	
86		0	85		1
	1			1	
85		1	84		3
	0			4	
85		1	80		1
	1			3	
84		0	83		0
	1			3	
83		1	80		1
	2			4	
81		2	84		2
	0			2	
81		0	86		1
	0			1	
81		1	85		2
	1			3	
82		1	82		1
	0			2	
82		1	80		0
	1			2	
83		1	82		0
	2			2	
81		1	80		0
	1			2	
82		0	82		0
	1			2	
81			84		
M = 82.9 S.D. = 1.44	M = .86	M = .76	M = 82.9 S.D. = 2.23	M = 2.36	M = .92

Mann-Whitney U (Ref. Siegel (12) - Non-Parametric Statistics For the Behavioral Sciences, McGraw-Hill, 1956)

Testing significance of differences between average rates-of-change (columns 2 and 5) for subjects A and B.

$U = 19$
$P = < .001$ (Significant difference exists)

The mean heart rate for the 15 entries for subject B is exactly the same as for subject A (82.9) but the variability is different (2.23).

One now asks the question, is subject A different in his rate-of-change of heart rate from subject B? To discover this, one can first find the first differential, or perhaps as it should be stated here, the first set of differences.[1] This procedure involves subtracting the first heart rate in a

[1] While heart rate itself may be assumed to be a first differential, it is treated here as basic data.

column from the second, ignoring signs, and recording the difference as shown in column 2 headed $\frac{d(HR)}{dt}$. Then subtract the second heart rate from the third and record it. Continuing this process provides a column of numbers which, if plotted against time, will yield the curve produced by the first differential or a curve of rate-of-change. However, since it is desirable to avoid dealing with curves, one simply averages this column of differences and arrives at the mean difference in heart rate during the 150 seconds, or the mean rate-of-change for the subject during this period. The signs in this computation are disregarded since the analyst is only interested in the rate-of-change and not the direction of the rate-of-change. In terms of calculus, one would be dealing with a non-directional derivative.

In a like manner, Table 6 shows that the column of first differences as well as its mean has also been calculated for subject B.

The question now is how does one arrive at a statement of the significance of difference between the mean rate-of-change in the heart rate of the two subjects? Usually a "t" test is used in such situations. However, one cannot apply a "t" test in its usual form here because the variability of heart rate is related to the degree of rate-of-change between the two subjects. Thus, when the subjects differ as to the rate-of-change, the homogeneity of variance assumption of "t" cannot be met. Further, there is some question as to whether the data are indeed at more than the ordinal level of measurement. Unless the interval level may be assumed, "t" cannot be justifiably used. Further, in future applications of this technique one may expect badly skewed distributions. Thus, for the general case, the usage of the parametric "t" test is not recommended as a test of significance. Instead, it is preferable to use its non-parametric counterpart, the Mann-Whitney U. (See Siegel 12). Applying the "U" test to the above data to determine the significance of the difference between the two mean rates of change, one finds that the absolute difference of 1.50 yields a "U" of 19. The difference in rate of change between the two subjects is highly significant ($P < .001$).

To measure the difference between the two subjects in terms of their rate-of-rate-of-change, one simply calculates the second differential or set of second differences. These are calculated from the column of first differences as shown in columns 3 and 6. Note that the technique in securing the second differences is exactly the same as was utilized in securing the column of first differences. The mean of the second differences column is secured on each subject and then their mean difference is tested for significance in the same manner as was the differences for rate-of-change information. The significance of difference of the rate-of-rate-of-change has not been worked out as an example for these data.

Some Computer Programs [1]

Time-Line Data Program: This program computes the means, variances, standard deviations, and standard scores for all incoming digital in-flight and appropriate ground-based medical data. During the Mercury missions, it was necessary to convert the analog medical data to digital form before this program could be used. An example of the type of outputs from this program is shown in Table 4.

Distribution Program: This program computes the means, variances, standard deviations, standard error of the mean, and critical ratios for skewness and kurtosis for a series of variables. The program is used mainly for assessing the shape of the distribution of selected data as indicated by the ratios for skewness and kurtosis.

The ratio of skewness indicates the degree of significance to which the particular distribution varies from the normal distribution and the direction in which the distribution varies (positively or negatively skewed). The critical ratio of kurtosis indicates the significance of the peakedness characteristic of the distribution; that is, the extent to which the distribution is flat (platykurtic), medium peaked (mesokurtic) or highly peaked (leptokurtic). These two characteristics are of interest due to assumptions of a normal distribution in many of the uses of the mean, variance, standard deviation, and standard error of the mean in statistical work. If the distribution is not normal, the critical ratios of skewness and kurtosis reveal this discrepancy, and a transformation of the scores is required in order to apply the analytical methods to the data appropriately.

Chi-Square and Frequency Distribution Program: This program computes the means and standard deviations, and classifies data or subjects in up to seven categories of response as well as the percent in each category. The program also computes a seven-category as well as a three-category chi-square as shown by Jones and Lindsey (8). Using the seven-category chi-square, one can test, for example, either for significant differences among up to seven different astronauts with respect to one selected type of measurement under identical conditions, or for significant changes taking place in one astronaut with respect to one selected type of measurement during seven different time-periods. All of these analyses assume independence of observations. Tables 7 and 8, respectively, illustrate these possibilities.

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[1] The author wishes to thank Doctors Benjamin Fruchter, D.V. Veldman and Earl Jennings, The University of Texas, Austin, Texas, who wrote several of the computer programs described.

Table 7 - Seven Different Astronauts, One Type Measurement, Identical Conditions

Seven-Category Chi-Square

Astronaut	1	2	3	4	5	6	7
Frequency	-	-	-	-	-	-	-
Percent	-	-	-	-	-	-	-

Table 8 - One Astronaut, One Type of Measurement, Seven Different Time Periods

Seven-Category Chi-Square

Time	1	2	3	4	5	6	7
Frequency	-	-	-	-	-	-	-
Percent	-	-	-	-	-	-	-

In applying this program, two separate chi-square tests are computed. First, the distribution of observations in seven categories is tested for fit against the expected distribution, usually one in which the probability of the observations (data) is equal in all categories. Thus, if there is actually no difference in the observations, each category has an equal opportunity of being the same magnitude. The statistical hypothesis tested is the null hypothesis, and the chi-square test then determines the probability that the observed distribution of data was derived from the theoretical distribution.

Second, the observations are classified into three categories. The computer program sums the observations (or data) in categories 1, 2, and 3; next it sums the data in category 4 (neutral category); and then it sums the data in categories 5, 6, and 7. The chi-square test is then applied to determine the significance of any difference in observations (or data) at either end or the middle of the distribution from the expected distribution. The resulting chi-square is printed, along with its level of significance. If the chi-square is significant at a pre-set level of probability, one is justified in rejecting the hypothesis that the observed distribution is derived from a population with equal frequencies in the three categories.

Three-Way Analysis of Variance Program: This program computes a three-way analysis of variance printing out a complete analysis of variance summary of all combinations of all means. It permits the application of a factorial design in which subjects or data can be classified along three separate dimensions; for example, two levels of performance (2 levels, operationally defined), three levels of oxygen content ($^{O}2_1$, $^{O}2_2$, and $^{O}2_3$) and three time periods (first fifteen minutes after zero "g", a fifteen minute sample one hour after zero "g", and a fifteen minute sample after two hours of zero "g").

Analysis of variance, then, permits a simultaneous comparison of data which are arranged in a particular manner and classified according to certain dimensions. All combinations of means are compared and contributions to variance are analyzed. Differences between means and combinations of means are analyzed for significance beyond those attributed to chance probability. If differences are significant, then inferences can be made for the classifications of the dimensions employed.

Correlation and Regression Program: This is a comprehensive computer program which computes the means and standard deviations for a series of variables, further computing the intercorrelation matrix and a complete multiple regression analysis which provides beta weights, multiple R squares, variance, multiple correlation, corrected multiple correlation, and R-ratio. The use for this program with in-flight medical data has been restricted to correlation. The correlation matrix provides the analyst with information as to how one measure relates to another for a given time period and condition over a sample of subjects. For example, one can solve for the degree of relationships among such measures as heart rate, respiration, acceleration, voice, performance, and carbon dioxide partial pressure.

Factor Analysis Program: This is a comprehensive computer program which computes means, standard deviations, principal axis factor analysis, varimax rotation, multiple regression, factor-score weight estimation, and standardized factor score computation. See Fruchter (7) for explanations of useful methods employed in factor analysis together with many examples of practical applications. Factor analysis is used to analyze the correlation matrix to determine the common factors basic to a set of different measurements. The solution is portrayed in the form shown in Table 9.

When conducting ground-based studies, for example, if the solution to a factor analysis problem resulted in a high rating on factor I under all conditions for both galvanic skin response (GSR) and muscle tone (EMG), one would have evidence that GSR could be measured without measuring EMG -- one of the measurements would not be required. This type of information can be very useful and valuable, in view of the current limitations on space, weight, and power within the capsule during space missions.

Table 9 - Factor Analysis Solution Format

Measure	Factor			
	I	II	III	h^2
Heart Rate	-	-	-	-
Respiration	-	-	-	-
Acceleration	-	-	-	-
Blood Pressure	-	-	-	-
Voice	-	-	-	-
Performance	-	-	-	-
Muscle Tone (EMG)	-	-	-	-
Electroencephalograph (EEG)	-	-	-	-
Galvanic Skin Response (GSR)	-	-	-	-

Statistical Model Limitations

Since much of the data represent time series, there are several inherent difficulties in analyzing them. The main difficulty is that repeated observations on a measure through time are often sequentially dependent. This sequential dependence, indicated by serial correlation, complicates the application of those statistical methods which assume independence of observations.

Increasing the time interval between observations usually reduces the amount of sequential dependency. Nevertheless, tests are required to determine if the observations (or measurements) selected for analysis are reasonably independent before statistical methods assuming independence can be applied. The principal method used in testing the serial dependency of observations is auto-correlation. This is accomplished by correlating the series with itself lagged one or more time periods.

CONCLUDING STATEMENTS

"The proper study of mankind is man," said Alexander Pope in 1733 in his famous poem, "Essay on Man". Today this observation can be extended to read, "The proper study of mankind in space is the study of man in space flight," for now it is possible to acquire highly important and accurate medical data from man in space flight. Nevertheless, in-flight medical data must be supplemented with ground-based medical data to assure maximal usefulness in consonance with the objectives of the NASA medical data program.

Appropriate NASA in-flight medical data from all NASA manned space flights have been prepared in a time-line format so that they are retrievable and "on-call" for computer inputs. These data lend themselves to many applications. First, they can be quickly brought to bear on any past or future problems concerning which they may have relevance. Second the particular method of analysis can be decided by the investigator since raw data in both analog and digital form are printed on each data sheet and recorded on magnetic tape. Third, if the investigator is opposed to any particular analytic technique which he believes to be invalid, he may treat the data using techniques and methods of his choosing subject to acceptance by the scientific community. Fourth, as improved methods of analysis are developed in the future, these newer methods can be applied using any combination of basic data included on the time-line data sheets. Finally, since standard scores are incorporated in the time-line data, scientists in disciplines other than medicine can, under certain circumstances, convert their data to standard scores and analyze for possible relationships that may exist.

Some NASA ground-based medical data have been prepared on data sheets and on magnetic tape in time-line format, but there is much work yet to be done both with respect to ground-based data and in-flight data. Nevertheless, it is encouraging to recognize that many types of graphical and mathematical/statistical analyses, as well as types yet to be conceptualized, can be programmed for accomplishment by a computer. These analyses can be performed very nearly in real-time if the investigator can determine in advance the hypotheses to be tested, the amount and kinds of data required, the methods to be employed, the significance levels to be accepted (e.g., .01, .05) and the type of computers and attendant computer programs required.

An ultimate goal is to develop a standardized method to record and store on magnetic tape all useful medical data on a world-wide basis for immediate retrieval in connection with past, current, and future medical problems. NASA has already taken a first step in this direction. The NASA

approach for space medicine data has been presented in the paper. It can serve as a building block and is open for review, criticism, revision, combination with other approaches, or redirection. These are some of the steps by which progress can be made toward the ultimate goal.

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APPENDIX A

SUPPLEMENTARY DEFINITIONS

Time-Line Medical Data: Data are prepared in time-line format when all available medical observations pertaining to a selected individual are presented on one data sheet representing a short interval of time (e.g., 10 seconds, one minute), and when consecutive data sheets are constructed representing successive time intervals. Within the context of this paper, the time-line in-flight medical data for each successive time interval includes such measurements as astronaut beat-to-beat heart rate, pulmonary ventilation rate, and various spacecraft environmental and astronaut performance measures.

Mercury Program: The NASA man-in-space program calling for suborbital one-man flights with Redstone booster in 1960-1961, and orbital one-man flights with the Atlas Booster in 1962. These flights were preceded by the two-orbital flights of chimpanzees.

Gemini Program: The NASA man-in-space program calling for orbital flights and rendezvous with two men in one vehicle, thus bridging the gap between the relatively simple Mercury missions and the more complex Apollo Lunar Program.

Apollo Program: This is the follow-on program of Mercury and Gemini manned space flights. The Apollo vehicle will have multimission capability including flights in the vicinity of the moon.

Mean: The mean is the arithmetic sum of all observations divided by the number of observations.

$$\bar{X} = \frac{\Sigma X}{n}$$

Variance: This statistic is a measure of variability of a set of observations or scores. It is the sum of the squares of the deviations of the observations from the mean divided by one less than the total number of observations or scores.

$$S^2 = \frac{\Sigma(X - \bar{X})^2}{n - 1}$$

Standard Deviation: This statistic is the positive square root of the variance. The standard deviation is considered the most stable and reliable measure of variability. The observations (or scores) falling within one standard deviation above the mean to one standard deviation below the mean encompass approximately two-thirds of the scores in a normal distribution.

$$S = \sqrt{\frac{\Sigma(X - \bar{X})^2}{n - 1}}$$

Standard Score: The score called standard score or relative deviate is symbolized by z and is defined as follows:

$$z = \frac{X - \bar{X}}{S}$$

where X = an original measurement, $\bar{X}$ = the mean of the distribution, and S = the standard deviation of the distribution.

Standardized Score: A standardized score is a score on a distribution with a mean of 50 and a standard deviation of 10, computed from a standard score as follows:

$$z = 50 + 10z$$

Standard Error of the Mean: This statistic indicates the reliability of the mean under consideration, and is computed by dividing the standard deviation by the square root of N (number of scores or observations). This is the standard deviation of an infinite set of means drawn from an infinite number of equal sized random samples, taken from the same population.

Normal Distribution: The normal distribution is a name applied to a specific bell-shaped curve which is symmetrical about the mean, with points of inflection at $\pm$ one standard deviation from the mean. Approximately 68 percent of the distribution is included in the interval $\pm$ one standard deviation, while approximately 97 percent is included in the interval $\pm$ three standard deviations. It has been found that random variation in many natural phenomena produces a curve similar to the normal distribution curve; consequently such a curve provides the basis for sampling procedures, testing hypotheses, and making statistical inferences.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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